A REVIEW ON ROBOTICS IN SPACE: PROGRESS AND FUTURE OF SPACE ROBOTICS

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Abstract

Robotics and autonomous systems have aided space exploration by allowing breakthrough research as well as satisfying human curiosity and the desire to explore novel places. This paper gives an overview of robotics in space as a fast-developing area, with a focus on the fundamentals. Concepts, terminology, historical context, and evolution are all covered in this section. It also has a technical roadmap taking into account important problems and priorities of the field. over the coming decades. Space robotics is a critical enabler for a variety of future robotic and crewed missions, space missions, as well as knowledge and technology transfer opportunities. Space robotics stimulates present and future generations to explore and critically analyses Science, Technology, Engineering, and Mathematics from a larger humanitarian perspective. Space robotics holds numerous critical enablers for a variety of future robotic and crewed space missions, as well as chances for knowledge and technology transfer to a variety of terrestrial industries.

Keywords *Robotics, Space Missions, Space Exploration.*

1.Introduction

In our day-to-day life, we use robotics in a variety of fields such as surgery, robotic limbs, satellites, etc. Robotics in space is aiding us in investigating our solar systems, different galaxies, and figuring out answers to fundamental scientific problems such as the origin, evolution, presence of life beyond Earth, universe formation, etc. As breakthroughs in this sector such as sensors, data management, mobility and flexibility, artificial intelligence, machine learning, and automation allow us to improve the overall performance of robots in space missions. Robots in space missions are playing an increasingly significant role in current and future missions as a result of rapid technological advancement. Space robotics appears to be a multi-disciplinary subject in which is developing and utilizing our engineering knowledge in space exploration, maintenance, crewed space missions, satellite maintenance, repairing, and the development, assembly of new robots, and other duties.

The overall human efficacy to operate and investigate in space will be enhanced by space robots, which will allow access to overcome the extreme environment of space. Robots, on the other hand, is economically practical for use because of their low cost and maintenance, and there is no risk of losing any of human live. Due to technological advancements, the cost of robot manufacturing and deployment in space is reducing, resulting in faster growth in space exploration and would assist us in establishing a new civilization on various planetary surfaces. Computerization in space robots can complete missions in a smooth and prompt manner, enhancing human competence and safety, and can complete required operations without any communication delays. Autonomy and locomotion are two traits that are frequently considered to be required for a spacecraft to be classed as a space robot. A space robot is meant to execute locomotion tasks (or mobility) such as drilling, grabbing, roving, manipulating, and by the nature of the mission, we have various levels of autonomy that span from human-operated to autonomously operated robots. A space robot can perform a variety of tasks owing to its varying levels of autonomy which are:

1. A robotic assistant that will support astronauts in doing certain tasks in a safe and prompt manner, with improved work quality and cost efficiency, utilizing a semi-autonomous to completely autonomous operation in the extreme environment of space.
2. A robotic assistant that aids us in a variety of tasks ranging from teleoperation to semi-autonomous operation.
3. A robotic explorer capable of exploring uncharted territory utilizing solely autonomous missions.

This paper reviews the present scenario of robotics in space.

Objective To review the progress and future of robotics in space.

Methodology Current scenarios of space robotic and space missions are reviewed for review, the descriptive method is used with comparison.

Material Selected published research paper as given in references.

2.1 Past and Current Robotics in Space Exploration

The ultimate ambition of humanity is to travel to the farthest reaches of the universe. Since the 1950s, space has provided us with a true, new exploring chance for illuminating the mysteries of the cosmos. From the late 1950s until the early 1960s, the goal of space exploration was to send humans to the moon and into Earth orbit. Robots have played a vital role in several space missions, including sample collection, robotic arms, surface rovers, and manipulators, thanks to locomotion systems. With technological advancement, we can search for new planets, moons, comets, and asteroids beyond Earth. For example, rather than a manipulator, the first genuine robotic locomotive system that was successfully deployed on an extra-terrestrial world was a scoop that was used as a sampling device on the Surveyor-3 lander that was dispatched to the Moon in 1967. Many missions followed this one, including LUNA 16 in 1970, which had the first planetary robotic arm-mounted drill, and LUNA 17 in 1970, which had the first planetary rover called Lunokhod-1. These missions take us on a fantastic voyage of scientific discovery (Y Gao, 2016).

As of 2017, Table 1 highlights the successful missions and robots flown on Earth orbit, the Moon, Mars, and small bodies. Robotic arms have been the primary means of increased mobility in orbital missions. To acquire movement on the planet, most existing missions have been using wheeled rovers or stationary landers outfitted with a robotic arm, drill, or sampler. Many current missions, particularly those aimed at planetary exploration, have yielded impressive results. For example, much of what we know about the Moon and Mars come from robotic, in-situ exploration. Notably, NASA has been at the forefront of Mars science with a succession of successful planetary rover missions, such as the MPF, MER, and MSL.

The amount of equipment carried by NASA's Mars rovers has been steadily growing over time. As a point of comparison, the MPF rover "Sojourner" was a small, short-lived mobile robot, but its main findings in geology, the possibility of past water on Mars, the magnetic characteristics of Martian dust, and the present Mars climate completely changed our understanding of the planet (Science,1997). The two identical MER rovers were much larger, allowing them to carry a much more capable science payload, including improved remote sensing and a more advanced robotic arm carrying in instruments for close-in/surface measurements, such as the Rock Abrasion Tool (RAT), Microscopic Imager, and Alpha Proton X-Ray Spectrometer (APXS) and Mossbauer Spectrometer.

Curiosity features several instruments that employ the robotic arm to obtain close-in measurements, including the Mars Hand Lens Imager (MAHLI), the Alpha Particle X-ray Spectrometer (APXS), and sample acquisition analysis (SAM) (Grotzinger JP et al., 2012). The Japanese Hayabusa robotic mission, which investigated and analyzed the Near-Earth Asteroid Itokawa in 2005 and returned the samples to Earth in 2010, is another important project. With a special issue in Science on the Itokawa research (science, 2006) and a later special issue in Science outlining the science from the recovered sample (science, 2001), the Hayabusa mission produced significant science. As an alternative data point, the Rosetta mission of the European Space Agency (ESA) attempted an exceedingly risky controlled landing on a comet nucleus. The “Philae” lander (Figure: 1) featured many remote sensing and in-situ equipment for compositional/gas analysis (e.g., COSAC, Ptolemy), drilling and sample retrieval, and surface measuring. Philae has achieved many scientific milestones, including the identification of organic compounds on the nucleus of 67P/Churyumov-Gerasimenko (Goesmann F. et al.,2015) (Wright IP. et al.,2015).

2.2 Future Robotic Missions

At present, space exploration is pioneering by robots. It does not mean that people are not capable; people can give us insight, flexibility, and encouragement in space missions at enormous costs. Human beings in space cannot live longer because they are delicate, tolerant to the severe environment of space, and many more things, while robots are easily used and maintenance is severely limited. We can combine robots, human intelligence, with the strength of robots - cyborgs will surpass the existing variety of robots in space in the future.

2.2.1 Mid-Term Planned Missions

Table 2 shows some robotic tasks proposed in the medium term by several foreign space organizations. What is obvious from a historical standpoint was that there was a far higher launch and diversity of players among few nations/organizations. In developing robotic missions which first target the Moon as testbeds, Spacefaring countries such as China and India are becoming more engaged. NASA and ESA are focusing on Mars and tiny bodies, which are also ahead of the space robotics game to tackle sample returns (Y. Gao, 2017).

2.2.2 Orbital Robotic Missions

There are many on-orbit applications that are expected to take place in 2025-2035 with sophisticated robotics capabilities. Operators can range from space bureaucracies to national governments to enterprises for these missions. The following mission focuses are proposed: removal of space waste, a rescue mission, planned orbit raising, deployment/assembly aids, repair, refueling and maintenance of orbit, mission evolution/adaptation, lifetime expansion, and re-orbiting. The ISS continues to offer the chance to undertake scientific research in space in the light of the unique characteristics, limitations and 5 stresses brought about by the environment. China is also creating a new mega platform for robotic solutions to progressively establish its program for space stations during the next decade. These robotic orbital missions can enable scientific exploration from Earth's orbits directly and indirectly (Y. Gao, 2017).

2.2.3 Planetary Robotic Missions

Newly proposed planetary missions are usually intended to achieve more interesting, ambitious scientific objectives and to build on the results from previous Moon, Mars, and smaller entities. NASA and ESA planned missions will show in the medium term, in comparison to their earlier missions, sophisticated science and robot technology, and are described as follows. The mission of NASA Osiris-Rex. This company was launched in 2016 and will arrive at Bennu-101955 in 2018, near Earth. The target will be mapped for 500 days (about 1 and a half years) and a small sample (< 2 kg) will be taken in 2023, then returned to the earth. TAGSAM (Touch and Go Sampling Acquisition Mechanism) uses the head of a sampler at the end of a robot arm. The sampling mechanism for this is a robotic arm. If the sample head detects an impact, a sample is obtained via a nitrogen system. TAGSAM can be utilized for the acquisition of a sample up to 3 times. Once the spaceship returns to Earth in 2023, the specimen will land the sample with a Sample Return Capsule (Stardust legacy). NASA Mission Insight (Figure 2) is a Mars landing on the surface of Mars planned for 2018. Insight incorporates several of the concepts of the previous lander mission of Phoenix but uses other equipment to examine the interior of the Martia. Two instruments are deployed using the deployment arm and the deployment camera (Y. Gao, 2017).:

1) The Seismic Experiment for Interior Structure, a seismographic device used to examine the Martian interior and seismic activity (directed by CNES, the French National Space Agency).
2) The Heat Flow and Physical Properties Probe (directed by DLR, Germany's National Space Agency), a self-burrowing mole that can drill up to 5 meters beneath the Martian surface to measure heat escaping from the interior (Banerdt WB, 2013). The Mars 2020 rover is the United States next mission to Mars. It has a lot in common with the MSL rover, but it has all new sensors.

The project will use the Sky crane deployment method, which involves lowering the rover to the surface of Mars with a cable from a rocket-powered hovering carrier. However, Terrain Relative Navigation improves the delivery approach by allowing the algorithm to avoid hazardous terrain while deciding where to lower the rover. Another notable advancement is that the rover will be equipped with a drill capable of scoring and caching samples for retrieval and return to Earth in the future. The new rover will have more autonomy as well including:

1. An onboard scheduler to make better use of time, energy, and data volume available (G. Rabideau, 2017);
2. The capacity to aim instruments such as SUPER CAM autonomously based on criteria supplied by scientists, which is an evolution of the AEGIS system already on MER (Estlin TA et al., 2012) and MSL (R. Francis et al., 2017). ExoMars 2020 (Figure 3) is currently the only European-funded mission that makes significant use of robotics in the form of an autonomous rover, ExoMars Phase 2 will be launched in March 2020, and will include an automated exobiology laboratory and a robotized drilling mechanism. Data from the ExoMars rover is, a new set of equipment will aid in the accurate visual and spectral description of Mars' surface, spanning from panoramic (meter) scales to smaller (sub-millimeter) studies to molecular studies for Organic compound identification.

Electromagnetic and neutron subsurface research will supplement the surface study and aid to better understand the depositional environment (e.g., sedimentary, volcanic, Aeolian). ESA's Mars robotic mission's distinctive contribution to exobiology is a significant step forward in the quest for past or current signs of life on Mars. Phobos Sample Return from ESA-Roscosmos. PHOOTPRINT (Figure 4) is another robotic mission under consideration, intending to return surface samples from Phobos (Mars' Moon). Robotic parts would be used on the trip to sample the surface under low gravity. The mission was first evaluated in two ESA concurrent design facility (CDF) studies, one industry study, and most recently in a CDF study with the expectation of becoming a combined mission with Ros's cosmos (Russian Space Agency) (Y. Gao, 2017).

2.2.4 Long-Term Mission

Table: 4 summarizes the idea in an organized manner about the concept to meet the long term need for exploration and science.

3. Space Robotics Categorization

3.1 Deep Space Exploration

Deep space starts from Earth surface at a distance of 2 million kilometers (about 0,01 AU), according to the International Telecommunications Union. Voyager 1 is the farthest space sonder humanity has yet built and launched. Research & development is vigorous and fast developing in this field. Future missions will require a deep space atomic clock, a gigantic solar sail, and a more powerful laser communications system to better communication, navigation, and propulsion. Isolation and confinement, certain radiations, a restricted environment, and gravity are some of the exploration's limitations.

3.2 In Lunar or Planetary Surface Vehicles

Surveying, observation, extraction, close examination of extra-terrestrial surfaces (including natural phenomena, terrain composition, and resources), constructing infrastructure on a planetary surface in preparation for future human arrival, or mining planetary resources are all tasks that planetary robots perform. We need good sensors in this type of vehicle for image-making, minerals & textures in rock surfaces, pathfinding for finding the best & safest map for the rover for exploration, to check various chemical compositions that are present, how radiation is present in the atmosphere, for finding living components of life such as water, and the weather conditions. They will also need certain automation systems to land safely on the surface and send back signals once they have done so.

3.3 Earth-Orbiting Robots for General Purpose

Its general functions for assembling solar panels and antennas, solar power satellites, space manufacturing, and space stations in space construction. Space construction and space servicing are two aspects of earth-orbiting. It performs the following functions in space servicing: deployment – this includes the precise positioning and orientation of new parts into existing space stations such as the International Space Station (ISS), as well as allowing us to extend or compress any antenna or solar panel for performing specific tasks, maintenance & repair – this includes the replacement of faulty circuit boards, increasing the life of the spacecraft. Now that we have travelled throughout our solar systems, we will need a good data analysis management system to analyze the terabytes of data that these missions have sent us and manage the informative data to improve future missions at a lower cost.

4. Evolution of Space Robotics

The new space exploration generation has travelled further into the solar system to address more ambitious research and research targets, therefore robots with a different locomotive and enhanced autonomy are expected to require more capable robots (Table 3). Over time, future space missions with increasingly tough aims need greater autonomy on the robots, which leads to evolution to robotic explorers and robotics aids.

4.1 Diversified Mobility and Access

Despite being successful in space exploration with the help of robots to this date, it has positively taken us to new heights of horizons. Further expansions in our knowledge of earth and other destinations, a solution has been proposed by the space community to explore the immersive zones of the unexplored terrains of different landscapes. Table 4 will supply us with a systematized view and summary of many ideas which have been proposed to date. There is a more comprehensive and system-level mobility concept is humanoid robotics which can be in the form of cyborgs and an excellent example is NASA's robonaut program (Y. Gao, 2017).

4.2 Increased Level of Autonomy

Humans can interact or use robots at a higher level as assistants/peers in mixed human-robot teams, or as goal-oriented completely autonomous explorers, thanks to increasing robotic autonomy. Robotic agents can manage their actions with the help of planning, scheduling, and resource management. Autonomous robots can persevere in uncertain execution settings thanks to robust task execution mechanisms. Navigation, mode and state estimation, and situational awareness capabilities, also known as integrated vehicle health management and prognostics, allow autonomous robots to track their status as well as their state in their immediate environment to operate effectively. This technology, when combined, allow space robots to have higher survivability, greater ability to complete their duties and accomplish science. Machine learning is often used in sensing and perception (e.g., machine vision) tasks. It has also been used in locomotion, such as to improve locomotion tactics or policies, as well as navigation. Machine learning continues to work on system-wide autonomy, planning, scheduling, and resource allocation. Learning for adaptability to individual users or specific tasks is an active topic of development in human-robot interaction. Coordination, control, and data assimilation are all possible uses for machine learning in multi-agent systems.

5. Technical Demands and Challenges

Current problem is that we are delaying our missions due to their size, width, power consumption, temperature, radiation, and vibration tolerance the technology gap between the ground station and space ready computing systems. Onboard reliability of communication hardware and software systems, we cannot contact them whenever we need to do or assign certain duties to do due to communication latency and bandwidth limits. When the systems are stationed on any planet the atmosphere can damage the hardware and software systems and their components, so that scientists come up with a solution of soft robotics system that allows us to overcome the physical effect and we may use it more in numerous ways. For deploying new systems in space stations or to establish a new base that can be far from earth, leading to the loss of our entire systems, we encounter correct rotating orientation issues. Space programs require people to going in space in suits and work, which dramatically affects job performance due to limited freedoms and humans tend to become fatigued quickly, which makes robots a suitable alternative in space.

The desire today is stronger than ever to go and explore space. A flourish of new nations, eager to test and prove their technology and to contribute towards an increasing array of knowledge have progressively joined past space powers. Commercial efforts will also look into space and actively promote the Moon and Mars as long-term human presence or dwelling destinations. If future exploration missions are crewed or robotic, space robots will always be willing to deliver 'avatars.' The robotic 'avatars' are supported or explored in situ by 'eyes,' 'ears,' (Y. Gao, 2016). The technical goals of robot technology are, in particular, to extend the human reach or access to space, to increase our ability to manipulate assets and resources, to prepare them for human arrival, to support human crews in the operations at their premises, and to improve mission efficiencies in all areas. Progress in the fields of robotics sensing and perception, mobility and manipulation, appointment and docking, independent on-board and ground functions and integration with human robots drive those objectives.

6. New Opportunities

6.1 Commercial Entry into Space Robotics

Space robotics change its competitive landscape. The main entities in space robotics have traditionally been domestic (e.g., NASA, Roscosmos, ESA, CNSA and JAXA). But more lately, business enterprises stated their intention and entered the region such as SpaceX and Blue Origin. Commercial companies explore and develop techniques for exploiting Moon and Asteroid resource streams. Moon Express, Deep Space Industries and Planetary Resources all strive to achieve the long-term aim of taking advantage of important moon elements. Usually, water-borne chemicals that enable on-the-ground synthesis of rocket fuels may be used beyond Earth (e.g., at the Moon, or Mars for a return vehicle). In the distant future, Helium 3 mining can offer vital fuel for fusion reactors from the Moon and from elsewhere. Finally, numerous extra-terrestrial worlds are home to scarce metals such as iron, nickel, cobalt, platinum, and titanium (Grotzinger JP. et al., 2012) which can fulfil our various needs for exploration and earth needs.

6.2 Knowledge and Technology

Transfer to Other Sectors than Space Exploration and Robotics is a part of the space industry that is heavily reliant on technology and has major challenges in meeting mission science goals. It is about upstream activities that do not provide much of a direct benefit to the space sector. However, it has a lot of potential for spin-off businesses, such as bringing in terrestrial breakthroughs from other industries and then spinning out the innovative technology. Current developments in space robotics programs, according to preliminary research, might have significant knock-on effects in a range of domains, including:

- **Emergency Services:** reduced risk to life, improved responsiveness, and more efficient deployment
- **Nuclear Facility Decommissioning**: for a post-operational clear-out, initial decommissioning, interim decommissioning, and final demolition
- **Deep Mining**: for excavation, exploration, refinement, in wind energy for turbine maintenance & inspection
- **Health & Care:** for robotic surgery, diagnostics, independent living, prosthetics, analysis, nursing systems and therapy.
- **Agriculture Industry**: for crop examination and precision farming.

7. Conclusions

Robot missions have enabled groundbreaking research in a variety of fields. Future robotics missions will continue to transform the way space is explored in more basic ways. They will allow exploration to occur more often, at lower costs in increasingly difficult and dynamics settings. These missions will not only continue our robotic research beyond the earth but will also aid human exploration beyond it. Robotics has a bright future in space exploration as well as in present. Those places where humans cannot reach easily due to our limitations and can be dangerous for a human mission, those places can be investigated easily based on a robotic mission. It will not only save our energy and time also it will make the mission more sophisticated and fruitful. Places like mars and mercury cannot be explored because of the time travel and threat to human life, but the same can be monitored by using robotic arms and humanoid rots. It means in the future; space exploration will be dependent on robotic missions.

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Table-1: robots flown to earth orbit, moon mars and small bodies as of 2018

Launch Year	Mission Name	Country	Target	Rover	Arm	Sampler	Drill
2018	Chang'E 4	China	Moon (Far side)	x			
2018	Insight	USA	Mars		x	x	x
2018(to arrive)	Osiris-Rex sample return	USA	NEA		x	x	
2018	Chandranyaan-2	India	Moon (Far side)	x			
2017	Chang'E 5	China	Moon	x	x	x	x
2016	Aolong-1	China	Earth orbit		x		
2004(arrived in 2014)	Rosetta	Europe	Comet		x	x	x
2013	Chang'E 3	China	Moon	x			
2011	Mars Science Laboratory (MSL)	USA	Mars	x	x	x	
2011	Robonaut	USA	ISS		x		
2008	Phoenix	USA	Mars		x	x	
2008	JEMRMS	Japan	ISS		x		
2007	Orbital Express	USA	Earth orbit		x		
2004	ROKVISS	Germany	ISS		x		
2003	Mars Exploration Rovers (MER)	USA	Mars	x	x	x	
2003	Hayabusa	Japan	Asteroid			x	
1997	ETS-VII	Japan	Earth orbit		x		
1996	Mars Pathfinder (MPF)	USA	Mars	x			
1993	Rotex	Germany	Earth orbit		x		
1981/2001/08	Canadarm1/2/Dextre @ISS	Canada	Earth orbit		x		
1975	Viking	USA	Mars		x	x	
1970/73	Luna 17/21	USSR	Moon	x			
1970/72/76	Luna 16/20/24	USSR	Moon		x	x	x
1967	Surveyor 3	USA	Moon			x	

Table 2: medium-term space robotics missions

Launch Year	Mission Name	Country	Target	Rover	Arm	Sampler	Drill
2025	Phobos Sample Return	Europe and Russia	Phobos		x	x	
2020+	Chinese Space Station	China	Earth Orbit		x		
2020	ExoMars 2020	Europe	Mars	x		x	x
2019	SLIM	Japan	Moon	x	x	x	x

Table 3: diversified locomotion for future space robots

Robotics Platform	Robotics Locomotion
Water surface	Vertical profiling float, Boat, ship
Manipulation	Arm, hand, gripper, sampler
Subsurface	Drill, submarine, submersible
Airborne	Quadcopter, helicopter, ornithopter, plane, glider, balloon, airbot
Land Surface	Wheeled rover, tracked rover, legged rover, rolling rover, hopper, hovercraft.

Table 4: long-term space robotic mission concepts

Destination	Proposed Mission Concepts	Proposed Robotic Locomotion
Gas giants	Exploration	Balloon
Europa/Enceladus	Exploration	Subsurface, Submarine, Hopper
Titan	Exploration	Aeroshell, Aerobot, Balloon, Lake Lander, Submarine, Ship, Cooperative robots
Asteroid	Sample return, ISRU	Rover, Hopper, Arm, Harpoon
Mercury	Exploration	Rover
Venus	Exploration	Balloon
Mars	Sample return, ISRU, crewed base	Aeroshell, Airplane, Helicopter, Balloon, Hopper, Swarms
Moon	Sample return, In-situ resource utilization (ISRU), exploration of permanently shaded craters, prepare for manned base	Rover, Arm, Sampler, Drill
Earth orbit	Space debris removal, On-orbit servicing & assembly	Arm, Hand/Gripper, Harpoon

Figure: 1 artistic depiction of philae lander at landing (courtesy esa)

Figure 2: insight lander with robotic instrument deployment arm and seismic sensor and heat flow sensor deployed (courtesy nasa).

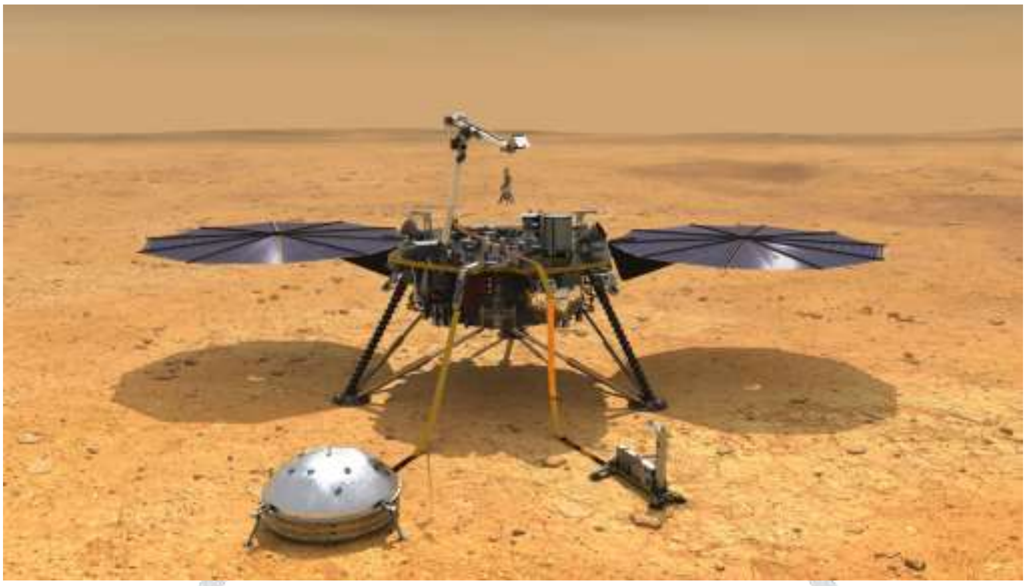

Figure 3 proposed: exomars 2020 with rover and deep drill assembly (courtesy esa)

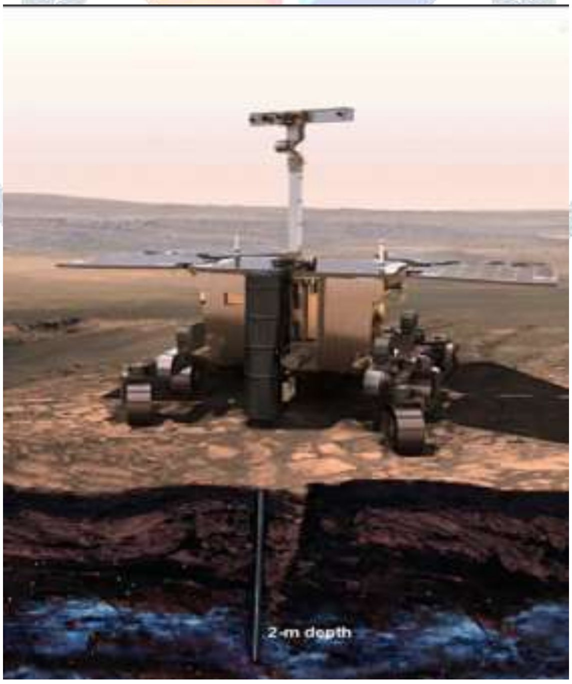

Figure 4: phobos sample return mission concept (courtesy airbus ds ltd)